**Inequality: A Neuroscience Perspective**

**Michael B. Miller and Michael S. Gazzaniga**

**Department of Psychological and Brain Sciences**

**University of California, Santa Barbara**

 It is impossible to ignore material inequality. Wealth, and the goods that come with it, are accumulating at the top of society while others seem to be struggling in the middle and bottom. It is a topic that currently consumes social scientists around the world and everyone wants to know more about how and why the 20th and 21st Century let this happen. This vastly complex and dynamic situation has multiple social, economical and political reasons that others will discuss in detail. Here we will focus on the biological issues, if any, both as they are understood now and are likely to appear with force in the future.

***General Background***

 It has been famously said that half of the population has below average intelligence. This quirky introduction to elementary statistics captures a reality of life. Many aspects of a biological being are normally distributed around a mean (e.g., height, size of antlers, speed of locomotion, etc.). Natural selection, of course, would not occur without normal variation within a species that leads to adaptations specifically well suited for its environment. This variation includes the development of brain structures and connections that give rise to individual differences in intelligence, reasoning, problem solving, social skills, and much more.

 The constitutive feature of our justice system, that all men are created equal, does not imply that all men are identical. Our chief concern in this review is to examine the biologic reality that all humans are not created equal. While most of the efforts in neuroscience have been directed toward determining the universal architecture of the brain, recent research has examined the variability between individuals in structure and function, which has led to a richer understanding of the link between the mind and the brain. Indeed, with the greater expansion of the cerebral cortex, there may be an evolutionary imperative for greater variability. The question is, what is the relationship between brain variability and social inequality? Do differences in socioeconomic status (SES) impact the developing brain? Does the known variability in the adult brain account for differences in an individual’s mental health, income and educational opportunities, and ability to co-exist within a community? Are there specialized neural adaptations that compel us to overcome social inequalities for the greater good? In short, is social inequality biologically inherent?

***The Developing Brain and Socioeconomic Factors***

To begin, the human brain is characterized by enormous variability in anatomy and connectivity (van Essen & Dierker, 2007; Mueller et al., 2013), and this variability is strongly related to individual variations in cognitive functioning and social behavior (Turken et al., 2008; Banissy et al., 2012; Golestani 2012; Barttfeld et al., 2013). At the same time, the overall growth and development of the brain is largely controlled by genetic processes that are, to a large extent, predetermined. Consistent with this and with the advent of human brain imaging in the 1980’s, the similarities and differences between monozygotic twins, dyzygotic twins, and non-related siblings was rendered measurable, with striking similarities being seen in monozygotic twins at the gross anatomical level (Oppenheim et al, 1998; Tramo et al 1998; Toga and Thompson, 2005). Taken together, these kinds of studies suggest a correspondence between a common structure and function.

At the same time, it is now known that significant epigenetic influences are in play during development. As the human fetus develops, a neural plate forms and folds in on itself, and eventually differentiates into distinct functional structures with neurons migrating in a largely precise, predictable, and universal fashion. And any deviation in this typically immutable genetic program, like genetic mutations or adverse prenatal environmental influences, can have severe developmental consequences (Fox, Levitt, & Nelson, 2010). However, the formation of synapses and the adjustment and pruning of axonal and dendritic extensions that form the basis of communication between these neurons are known to be heavily dependent on experience (Wiesel & Hubel, 1965; Bourgeois, Goldman-Rakic, & Rakic, 1999; Fox, Levitt, & Nelson, 2010). Also, it is known that genetic factors have much less influence on association cortex than on unimodal cortex leading to greater diversity of neural connections within the association cortex as a result of environmental factors (Brun et al., 2009; Petanjek et al., 2011).

The inherent variability of the connections within the association cortex was recently highlighted in a study by Mueller and colleagues (2013). They examined the intrinsic functional connectivity of the whole brain within 23 healthy subjects that were scanned five times over a 6-month period.[[1]](#footnote-1) They measured the inter-individual variability of networks of functionally connected brain regions that spanned across the association cortex (such as the frontal-parietal network) and found that they were significantly more variable than networks confined to unimodal regions (such as the visual network). Mueller and colleagues observed that these variable brain regions confined to the frontal, parietal, and temporal lobes, were also brain regions that are known to be phylogenetically late developing. So, they set out to test this relationship by statistically comparing a map of the extent of variability in functional connectivity between individuals with a map of cortical expansion between an adult macaque monkey and a typical human adult. Indeed, they found that the regions that were most variable in functional connectivity were the same regions that showed greater cortical expansion from the macaque brain to the human brain. One way to interpret that relationship is that variability in functional connectivity may have been imperative for the evolution of the association cortex.

 It is important to note that these variations within the association cortex, regions critical for reasoning and problem-solving skills, may be directly influenced by socio-economic status. This may in turn further affect educational outcomes, health outcomes, mating opportunities, etc. As Mueller and colleagues suggest, the protracted maturation of these regions, the weaker genetic influence on structure, and the over-production of synapses may “enable more variable impact of postnatal environment factors that lead to the diversity of neural connections beyond their genetic determination” (Mueller et al., 2013, p. 586).

Is there evidence of physiological harm that comes from exposure to deprivation? Several years ago, Martha Farah and colleagues (2006) conducted a large-scale study measuring the effects of childhood poverty on several neurocognitive systems. They found that higher SES was associated with better performance on tasks involving left perisylvian cortex/language processes, medial temporal lobe/memory systems, lateral prefrontal cortex/working memory, and anterior cingulate/cognitive control. More recent neuroimaging studies have recently demonstrated that socioeconomic factors above and beyond genetic history and nutritional status directly impacted brain morphometry, with small differences in income among children from lower income families being associated with large differences in brain surface areas supporting language, reading, executive functions and spatial skills (Noble et al., in press; Brito & Noble, 2014). These authors suggest that the key factors affecting brain development among underprivileged children is the stress of living under those conditions and the impoverished linguistic environment (see model below.)



Changes in social status can quickly and effectively alter neural states, even in the adult brain. Many species, other than humans, form social hierarchies in which males battle for dominance and the opportunity to reproduce. A recent study examined the changes in neural networks as a result of a loss in social status among African cichlid fish (Maruska et al., 2013). By manipulating the social environment, Maruska and colleagues were able to demonstrate that a descent in rank among males produced profound changes in behavior, circulating steroids and gene expression within discrete brain regions known to regulate social behaviors. Within minutes of losing social status, male fish lost their bright body coloration, switched to submissive behavior, and expressed higher levels of cortisol in comparison to control fish. So the social environment cannot only have a negative impact on the developing brain, but changes in social status may also negatively affect the adult brain.

But the effects of the environment on brain development are not just negative ones. There are also known positive effects on brain development due to enriched versus impoverished environments. For example, several studies have reported that musical training at an early age leads to changes in structural brain development (Gaser & Schlaug, 2003; Bengtsson et al., 2005; Hyde et al., 2009; Skoe & Kraus, 2012; Bailey, Zatorre, & Penhune, 2014; Moore et al., 2014; Hudziak et al., 2014). Hudziak and colleagues (2014) recently examined the structural MRI scans of 232 youths, ranging in age from 6 to 18 years, that were obtained from the National Institutes of Health (NIH) Magnetic Resonance Imaging Study of Normal Brain Development (Evans, 2006). Along with the brain data, IQ and musical training data were also available for these subjects. Hudziak and colleagues discovered that years of musical training at an early age was associated with an increased rate of cortical thickness maturation throughout widespread regions of the prefrontal and parietal cortex.

It is important to note, however, that not all children respond to the environment in the same way. Indeed, there are plenty of stories about children growing up under conditions of extreme abuse, stress, and poverty, yet developing into prosperous, responsible, and intelligent adults (New York Times, 4/30/2006). During the past decade, neuroscientist have begun to examine the neurobiological and genetic contributors to resiliency that is commonly found in those individuals that seem to positively adapt to negative environmental influences, including severe stress and impoverishment (Cicchetti, 2010). For example, Caspi and colleagues (2002; 2003) studied a large sample of adults, many of whom were maltreated as children. They found that resilient adults, those who were maltreated while growing up but failed to develop antisocial problems, tended to have a genotype that conferred high levels of the metabolizing neurotransmitter MAOA (Caspi et al., 2002). Furthermore, they found that stressful life events early in development were more likely to lead to depression in adulthood if the individual had one or two copies of the short allele of the serotonin transporter 5-HT T (Caspi et al., 2003). As Cicchetti notes, “discovering how maltreated children develop and function resiliently despite experiencing a multitude of stressors offers considerable promise for elucidating developmental theories of coping and for prevention and intervention.” (Cicchetti, 2010, p. 148)

As we have reviewed to this point, we may be endowed with a certain genetic blueprint, but the expression of those genes and the synaptic conductances and connections that are formed may be more or less experience dependent – meaning that unequal experiences and environments can express itself in the development of the brain. It’s also the case that variability in the adult human brain, no matter the source of that variability, may lead to unequal outcomes. We turn our attention to that possibility next.

***Variability in Brain Structure and Function and Its Impact on Inequality***

 We discovered several years ago that the typical method of representing brain activity during a higher-order cognitive task, i.e., a group map or a map of activity averaged across many individuals, does not necessarily represent the individual patterns of activity that make up that group map (Miller et al. 2002; Miller et al., 2009). And the differences are extensive. Still, it is the case that common areas of activation are useful for understanding the functionality of a given brain region, and it is also the case that tracking individual differences in cognitive performance with individual differences in brain activity can be an effective way to link the mind with a common a brain region. But it is also the case that two subjects can have identical memory performance, yet one individual shows a strong pattern of activity restricted to the parietal lobe while the other individual shows a strong pattern of activity restricted to the prefrontal cortex. Further, we found that if we brought the subjects back 6 months later and repeated the scanning, the subjects produced similar patterns of activity, indicating that the differences between the individuals do not represent measurement noise but some systematic difference between them. Subsequent studies by our group indicate that several factors can contribute to the source of this variability that have very little to do with the performance on a given task, including differences in cognitive style, personality, state of mind (such as coffee consumption), white matter connectivity, and much more (Miller et al., 2012; Turner et al., in prep). As well as we can determine, brain activity is not just a reflection of task performance, but it reflects an interaction between task performance and the personality and life experiences of the individual.

Differences in functional activity, however, can also be an indication of something dysfunctional within a certain segment of the population. In a recent study, we examined the brain activity of 44 prisoners at a high security prison while performing a simple go/no-go task (Freeman et al., 2014). Half of these prisoners scored high on a scale of psychopathy, while the other half scored low. We performed an independent component analysis of the task activations within the default mode network (DMN). This network of brain regions was discovered to be more active during rest than during a goal-directed task (Raichle et al., 2001), and its activity has been associated with introspection, simulating the future, and empathy with others (Buckner et al., 2008). We found subregions of the DMN that failed to deactivate below baseline in the high-psychopathy group but not in the low-psychopathy group. This was particularly the case in posteromedial cortical regions that have been associated with affective/interpersonal traits of psychopaths, i.e., a lack of concern for others. Findings like these not only provide insight into the nature of brain variability, but it also has possible implications regarding culpability within a society (Gazzaniga, 2012). Can we hold an individual to the same standards of behavior if they happen to be hard wired differently?

***Neuroscience Methods Used to Predict Social and Cognitive Outcomes***

Noninvasive neuroimaging has been able to take advantage of individual differences in brain structure and function to predict future outcomes on a variety of measures that directly affects equality between individuals. For example, Hoeft and colleagues (2011) scanned dyslexic individuals and found that greater activation in the right inferior frontal gyrus for a phonological task predicted greater gains in reading 2.5 years later. Similarly, Supekar and colleagues (2013) scanned normal students and found that greater gray matter volume in the right hippocampus predicted greater performance gains in students after 8 weeks of math tutoring.

As Gabrieli, Ghosh, and Whitfield-Gabrieli (2015) recently noted, the ultimate goal of these efforts is to use neuromarkers to predict education and health outcomes for a single individual. Such research can be conceptualized as comprising three phases. The first phase involves data exploration, i.e., discovering the associations between brain regions and known outcomes. The second phase is a cross validation routine that separates data into a training group and a testing group, and then building a model based on the training group and testing it out on the test group. The third phase is determining how generalizable that model is by testing it out on completely new data. As Gabrieli and colleagues discussed in their recent review, such efforts have used neuroimaging data to predict future outcomes in cognitive performance in adults, future learning and education in children, future criminality, future health, future response to treatment, and future relapse for alcohol, drug addiction, smoking, and diet. Further, they were able to demonstrate that these neuromarkers provide better predictors of these future outcomes than more traditional behavioral measures. The potential for knowledge of this kind, to use existing brain data on an individual to predict future unintended inequality, may be helpful, but may also be concerning.

***Is There a Natural Aversion to Inequality?***

Given the range of brain variability and its potential impact on social inequality, can a natural aversion to inequality rescue those people that are less fortunate than others? After all, we as a society used the principle “all men are created equal” to guide our laws and form our government. But, are we necessarily born with a desire to be fair with one another? Are we really hard-wired in some way that drives us to make sure that other people within our community have an equal share of the pot? The study of fairness in humans has been studied extensively over the years by psychologists, anthropologists, political scientists, economists, and more recently, by neuroscientists. These studies often use paradigms like the dictator game, in which the “proposer” determines the allocation of some reward to himself/herself and to another individual, often called the “responder.” Indeed, results from these studies demonstrate that while proposers often choose to keep most of the rewards, the second most common choice is to split the rewards evenly between the proposer and the responder (Fehr & Schmidt, 1999).

This kind of result across many species and across divergent human cultures has led some to suggest that a preference for fairness and an aversion to inequality may have evolved in order to promote social cooperation among conspecifics for the greater good of the local community. In fact, it has often been demonstrated that humans will provide a benefit to another person at a cost to themselves, and they will do so in a way that excludes alternative explanations for this altruistic behavior, such as kinship welfare, enhancing social image and reciprocity (Fehr & Schmidt, 1999; Dawes et al., 2007). John O’Doherty and colleagues at Caltech have recently studied the possible neural mechanisms of such an evolved system using fMRI. They found that the ventral striatum and the ventral medial prefrontal cortex, two regions that are known to be sensitive to monetary and primary rewards in social and non-social contexts, were more responsive to those individuals that transfer rewards to others than to themselves (Tricomi et al., 2010).

But are we really born with a sense of fairness? Revealing the bubbling mental life of babies and young children has been an exciting enterprise, especially in the last 20 years. The newborn stands as an important point of contrast between animal research and studies on the normal adult. Early detection of mental states in infants suggests the range of mental states humans are born with, while testing throughout childhood reveals how these early mental dispositions are modified by epigenetic forces. Nowhere are these contrasts more evident than on the issue of inequality aversion.

Mark Sheskin, Paul Bloom and Karen Wynn (2014) recently found that while young children dislike getting less than others, they are not averse to other children getting less than themselves. In fact, when 5- to 6-year-old children are given the choice between equal payouts of a reward between themselves and another child (e.g., 5 tokens each) versus unequal payouts of a reward (e.g., 4 tokens to themselves and only 2 tokens to the others), the children will often choose the unequal payouts even at a cost to themselves. It appears that a sense of fairness in children does not appear until the children reach an age when they become increasingly dependent on social interactions with their peers. So, an aversion to inequality may not be something that we are born with, but something that develops over the course of our life history (Sheskin et al., 2014).

Further, not all adults behave in an altruistic manner. Like most other human characteristics, the tendency to act in an altruistic manner can vary greatly from individual to individual, from the extreme psychopath with little regard for others to the highly altruistic individual that is willing to donate a kidney to a stranger. Marsh and colleagues (2014) recently examined the brains of extraordinary altruists, individuals that had actually donated their kidneys to strangers, and matched controls. They found that altruists showed enhanced volume of the right amygdala and enhanced neural responsiveness to fearful face expressions compared to matched controls, exactly the opposite result that is found with psychopaths.

In all, what remains to be determined is how the variability in brain networks between individuals might contribute to variations in an individual’s aversion to inequality. As far as we can determine, while an aversion to inequality may be useful in overcoming our inherent biological differences that contribute to social inequalities, this aversion does not appear to be something that we are born with nor is it something that comes in equal parts among all adults.

***Summary***

We propose that more studies on the individual variability in brain structure and function are needed to better understand this emerging relationship between brain function and social inequality. The early evidence suggests that (a) SES may significantly impact brain development; that (b) resiliency to the environment, however, may have a genetic and neural basis; that (c) variability in the adult brain may be predictive of future outcomes in education, health, and sociability; that (d) the neural basis for an aversion to inequality, which may help resolve social inequities due to brain variability, may not be something that we are born with and may not be something that we share equally. Clearly, much is still to be learned and resolved, and the big questions remain to be answered. Is social inequality biologically inherent? And, can we, or should we, intervene on a neural basis to reduce these inequalities?

***Acknowledgments***

This work was supported by the Institute for Collaborative Biotechnologies through grant W911NF-09-0001 from the U.S. Army Research Office. The content of the information does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred.

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1. Functional connectivity is a measure of the correlation between any two brain regions in spontaneous neural activity that can occur with no task instructions whatsoever, and these measures reveal several intrinsic brain networks that may critically work together during a variety of cognitive functions (Bassett & Gazzaniga, 2011). [↑](#footnote-ref-1)